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| | 5f. WORK UNIT NUMBER |

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| Optical Society of America<br>2010 Massachusetts Ave., NW<br><br>Washington, DC 20036 -1012 | |
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14. ABSTRACT

In recent years with the advent of high Q optical and mechanical micro-cavities, it has been possible to observe coupling between optical radiation and the mechanical modes in moveable structures in fine detail. Light when confined within a resonator exerts radiation pressure on the mechanical structure which gives rise to the effect of dynamic back-action. This leads to, among other things, parametric instability and opto-mechanical back-action cooling. Recently the dynamic manifestations of radiation pressure forces on micro- and Nano-mechanical objects

15. SUBJECT TERMS

Final Report on Cavity Optomechanics

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 15. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT | b. ABSTRACT | c. THIS PAGE | | | Elizabeth Rogan |
| UU | UU | UU | UU | | 19b. TELEPHONE NUMBER<br>202-416-1484 |

Standard Form 298 (Rev 8/98)
Prescribed by ANSI Std. Z39.18

## Report Title

Final Report: Organization of 2012 Cavity Optomechanics Incubator Meeting


## ABSTRACT

In recent years with the advent of high Q optical and mechanical micro-cavities, it has been possible to observe coupling between optical radiation and the mechanical modes in moveable structures in fine detail. Light when confined within a resonator exerts radiation pressure on the mechanical structure which gives rise to the effect of dynamic back-action. This leads to, among other things, parametric instability and opto-mechanical back-action cooling. Recently the dynamic manifestations of radiation pressure forces on micro- and Nano-mechanical objects have become an experimental reality. These observations have created a great deal of interest in exploiting these effects to study fundamental properties of light and mechanical systems and research in this topic has grown quickly over the past few years to include areas such as optical micro and nano-mechanical resonators, entanglement, generation of squeezed states of light, measurements at or beyond the standard quantum limit, single photon non-linearities, and fundamental sources leading to decoherence. In this incubator meeting, we examined the emerging areas referred to as cavity opto-mechanics and cavity quantum opto-mechanics with the goal of discussing the latest advances which define the state of the art, and exploring the opportunities afforded by this new technology to better understand coupled systems and the quantum phenomena encompassing both optical and mechanical systems.


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## Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

### (a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

**TOTAL:**

**Number of Papers published in peer-reviewed journals:**

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### (b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

**TOTAL:**

**Number of Papers published in non peer-reviewed journals:**

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### (c) Presentations

**Number of Presentations:** 0.00

## Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

**TOTAL:**

**Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):**

## Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received Paper

**TOTAL:**

**Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):**

## (d) Manuscripts

Received Paper

**TOTAL:**

**Number of Manuscripts:**

## Books

Received Book

**TOTAL:**

Received Book Chapter

**TOTAL:**

## Patents Submitted

## Patents Awarded

## Awards

## Graduate Students

| NAME | PERCENT_SUPPORTED |
| --- | --- |
| **FTE Equivalent:** | |
| **Total Number:** | |

## Names of Post Doctorates

| NAME | PERCENT_SUPPORTED |
| --- | --- |
| **FTE Equivalent:** | |
| **Total Number:** | |

## Names of Faculty Supported

| NAME | PERCENT_SUPPORTED | National Academy Member |
|---|---|---|
| Prof. Markus Aspelmeyer | 1.00 | No |
| Prof. Pierre Meystre | 1.00 | Yes |
| **FTE Equivalent:** | **2.00** | |
| **Total Number:** | **2** | |

## Names of Under Graduate students supported

| NAME | PERCENT_SUPPORTED |
|---|---|
| **FTE Equivalent:** | |
| **Total Number:** | |

## Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: ...... 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 0.00

## Names of Personnel receiving masters degrees

| NAME |
|---|
| **Total Number:** |

## Names of personnel receiving PHDs

| NAME |
|---|
| **Total Number:** |

## Names of other research staff

| NAME | PERCENT_SUPPORTED |
|---|---|
| **FTE Equivalent:** | |
| **Total Number:** | |

## Sub Contractors (DD882)

# Inventions (DD882)

# Scientific Progress

# Technology Transfer

The format of the Cavity Optomechanics Incubator Meeting consisted of a series of two-hour long round tables discussions, each opened by one invited 45-minute overview presentation that helped frame the discussion in a balanced way, followed by brief, 3 slides presentation-long by interested participants and an open discussion
Topics discussed:

1. On-Chip Optomechanics: new ideas for classical and quantum information processing architectures (e.g. classical: optical nonlinearities, optical memory; quantum: coherent light-matter interfaces, quantum memories, single-photon nonlinearities); coupled systems such as arrays; manybody physics, etc.
Overview: Dr. Oskar Painter, Caltech
2. Multimode Phonon Physics: time dependent systems, phonon pulses, pulsed optomechanics; toward quantum acoustics, etc.
Overview: Dr. Kurt Jacobs, Boston University
3. Coherent Light-Matter Interfaces: mechanical to optical, mechanical to spins, mechanical to matter-wave fields; BECs, ultra cold atoms, hybrid systems, etc.
Overview: Dr. Olivier Arcizet, Grenoble
4. Tests of Fundamental Theories: fundamental sources of decoherence, predictions of quantum gravity. What can large masses do for you? Is it useful to have Planck mass objects operating in the quantum regime? What can large accelerations do for you?
Overview: Dr. Oriol Romero-Isart, Max-Planck Institute for Quantum Optics, Garching
5. Theoretical Challenges and New Directions: new types of couplings, nonlinear effects, single phonon physics, quantum control, nonclassical states, etc.
Overview: Dr. Aash Clerk, McGill University, Montreal
6. Experimental Challenges and New Directions: new systems, larger systems, graphene, mechanical nonlinearities, etc.
Overview: Dr. Tobias Kippenberg, EPFL Lausanne
7. Mechanical Sensing/Metrology in the Quantum Regime: what are the prospects?
Overview: Dr. Keith Schwab, Caltech

# Final Report on 2012 Cavity Optomechanics Incubator Meeting

Submitted to:

Dr. Paul M. Baker

Atomic and Molecular Program Manager
Army Research Office (ARO)
4300 S. Miami Blvd.
Durham, NC 27703-9142

From:

Principal Investigator: Elizabeth A. Rogan

Optical Society of America
2010 Massachusetts Ave NW
Washington, D.C. 20036

**Meeting**
**30 September - 2 October 2012**
**OSA Headquarters**
**Washington, DC**

## Post-Meeting Stats:

| Incubator Meeting | Hosts | Participants | Total | | OSA MBR | N-MBR | | INTL | US | | CORP | GOV | ACAD | STUD | | Local | NonLocal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cavity Optomechanics | 2 | 43 | 45 | | 12 | 33 | | 17 | 28 | | 1 | 4 | 40 | 3 | | 2 | 43 |

**The below ratings are on a 0-5 scale, feedback gathered from participants and averaged**

| Quality of Speakers | | Interaction/ Networking Opportunities | | DC Location | | Expected/Quality Attendees | | International Participation | |
|---|---|---|---|---|---|---|---|---|---|
| **Data** | **Rating** | **Data** | **Rating** | **Data** | **Rating** | **Data** | **Rating** | **Data** | **Rating** |
| Excellent | 5 | Excellent | 5 | Excellent | 5 | Agree | 4 | Strongly Agree | 5 |

<u>Background</u>

The Optical Society of America is a scientific society of over 18,500 members with an executive office in Washington, D.C. The Society is dedicated to increasing and diffusing the knowledge of optics in all its branches, pure and applied. The membership consists primarily of physicists, engineers, and other physical and biological scientists.

The Society sponsors topical meetings on subjects in which many rapid advances are taking place so that contributors to the field may interchange ideas to their mutual benefit. The format of such meetings usually consists of invited and contributed papers. Contributed papers are reviewed. Summaries of papers as submitted by authors are collected and published. Publications are provided to participants and are also available to others interested in the meeting subject. These topical meetings have provided much stimulus in research areas such as: integrated optics, optical fiber communication, optical storage of digital data, atmospheric transmission, reconstruction from projections, image processing, and picosecond phenomena.

Technical Scope

In recent years with the advent of high Q optical and mechanical micro-cavities, it has been possible to observe coupling between optical radiation and the mechanical modes in moveable structures in fine detail. Light when confined within a resonator exerts radiation pressure on the mechanical structure which gives rise to the effect of dynamic back-action. This leads to, among other things, parametric instability and opto-mechanical back-action cooling. Recently the dynamic manifestations of radiation pressure forces on micro- and Nano-mechanical objects have become an experimental reality. These observations have created a great deal of interest in exploiting these effects to study fundamental properties of light and mechanical systems and research in this topic has grown quickly over the past few years to include areas such as optical micro and nano-mechanical resonators, entanglement, generation of squeezed states of light, measurements at or beyond the standard quantum limit, single photon non-linearities, and fundamental sources leading to decoherence. In this incubator meeting, we will examine the emerging areas referred to as cavity opto-mechanics and cavity quantum opto-mechanics with the goal of discussing the latest advances which define the state of the art, and exploring the opportunities afforded by this new technology to better understand coupled systems and the quantum phenomena encompassing both optical and mechanical systems.

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   *Overview: Dr. Oriol Romero-Isart, Max-Planck Institute for Quantum Optics, Garching*

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7. **Mechanical Sensing/Metrology in the Quantum Regime**: what are the prospects?
   *Overview: Dr. Keith Schwab, Caltech*

Meeting Organization

This incubator meeting is sponsored by the Optical Society of America.

The organization of the technical and scientific program led by meeting hosts:

Markus Aspelmeyer, *University of Vienna, Austria*
Pierre Meystre, *University of Arizona, USA*

### Final Registration

| First Name | Last Name | Org Name | Country |
|---|---|---|---|
| Jamil | Abo-Shaeer | Defense Advanced Res Projects Agency | UNITED STATES |
| Girish | Agarwal | Oklahoma State University | UNITED STATES |
| Markus | Aspelmeyer | University of Vienna | AUSTRIA |
| Gaurav | Bahl | University of Illinois at Urbana Champaign | UNITED STATES |
| Paul | Baker | Army Research Office | UNITED STATES |
| Paul | Barclay | University of Calgary | CANADA |
| Sunil | Bhave | Cornell University | UNITED STATES |
| Miles | Blencowe | Dartmouth College | UNITED STATES |
| Ania | Bleszynski Jayich | University of California Santa Barbara | UNITED STATES |
| Tal | Carmon | University of Michigan | UNITED STATES |
| Hengky | Chandrahalim | University of Michigan | UNITED STATES |
| Yanbei | Chen | California Institute of Technology | UNITED STATES |
| Aashish | Clerk | McGill University | CANADA |
| Pierre-Francois | Cohadon | Ecole Normale Superieure | FRANCE |
| Thomas | Corbitt | Louisiana State University | UNITED STATES |
| Tatjana | Curcic | AFOSR | UNITED STATES |
| Mark | Dong | University of Michigan | UNITED STATES |
| Klemens | Hammerer | Leibniz University Hannover | GERMANY |
| Kurt | Jacobs | University of Massachusetts Boston | UNITED STATES |

| | | | |
|---|---|---|---|
| Rina | Kanamoto | Meiji University | JAPAN |
| Mo | Li | University of Minnesota | UNITED STATES |
| Florian | Marquardt | University of Erlangen | GERMANY |
| Leopoldo | Martin | La Laguna University | UNITED STATES |
| Nergis | Mavalvala | Massachusetts Institute of Technology | UNITED STATES |
| David | McAuslan | University of Queensland | AUSTRALIA |
| David | McClelland | Australian National University | AUSTRALIA |
| Michael | Metcalfe | Booz Allen Hamilton, Inc. | UNITED STATES |
| Pierre | Meystre | University of Arizona | UNITED STATES |
| Haixing | Miao | Caltech | UNITED STATES |
| Gerard | Milburn | University of Queensland | AUSTRALIA |
| Preeti | Ovartchaiyapong | University of California Santa Barbara | UNITED STATES |
| Thomas | Purdy | JILA | UNITED STATES |
| Oriol | Romero-Isart | Max Planck Institute of Quantum Optics | GERMANY |
| Keith | Schwab | California Institute of Technology | UNITED STATES |
| Signe | Seidelin | Université Joseph Fourier (Grenoble I) | FRANCE |
| Kartik | Srinivasan | National Inst of Standards & Technology | UNITED STATES |
| Dan | Stamper-Kurn | University of California Berkeley | UNITED STATES |
| Charles | Tahan | LPS | UNITED STATES |
| Michael | Tobar | The University of Western Australia | AUSTRALIA |
| Paolo | Tombesi | Universita di Camerino | ITALY |
| Herre | van der Zant | Delft University of Technology | NETHERLANDS |
| Mukund | Vengalattore | Cornell University | UNITED STATES |
| Ewold | Verhagen | Ecole Polytechnique Federale de Lausanne | SWITZERLAND |
| David | Vitali | Universita di Camerino | ITALY |
| Ignacio | Wilson-Rae | TU Munich | GERMANY |
| huan | yang | Caltech | UNITED STATES |